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PRELIMINARY EVALUATION OF THE IMPLICATIONS OF AIRBORNE ASBESTOS EXPOSURE CONCENTRATIONS OBSERVED DURING SIMULATION OF A SELECTED SET OF COMMON, OUTDOOR RESIDENTIAL ACTIVITIES CONDUCTED AT THE NORTH RIDGE ESTATES SITE, KLAMATH FALLS, OREGON

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1. EXECUTIVE SUMMARY

This report presents an evaluation of the results from a special study by the U.S. Environmental Protection Agency (EPA) conducted at the North Ridge Estates Site in Klamath Falls, Oregon on July 20-22, 2004. Exposure and risk estimates extrapolated from the EPA study are also compared with exposure and risk estimates presented in the recent, Preliminary Soil Report for the site while addressing the potential limitations of such comparisons.

Comparing results between the EPA study and the Preliminary Soil Report provides an improved understanding of the nature of uncertainties associated with projecting exposures and their attendant risks at the site. Consequently, by reconciling measured and modeled results from these two studies, a revised set of bounding (conservative, upper limit) exposure and risk estimates are developed and presented for the site. Among other things, the revised estimates better account for contributions from amphibole asbestos, which has occasionally been observed in a small number of samples from several of the various sampling campaigns that have been conducted at the site. Thus, the occurrence of amphibole asbestos among such data sets is also reviewed.

EPA Study Design

During the EPA special study, contractors (in full protective gear) conducted simulations of a selected set of dust generating activities performed by residents at the site. During each simulation, air samples were collected from the breathing zone of the contractor conducting the activity of interest. The objective was to obtain measurements of airborne concentrations of asbestos that would bound exposures and the attendant risks potentially experienced by residents while conducting the activities simulated.

During the EPA study, three activities were selected for simulation:

1. a child-playing in dirt, during which a gallon bucket was repeatedly filled and emptied;
2. weed trimming using a nylon cord weed trimmer; and
3. rototilling using a commercially available rototiller.

As previously indicated, the EPA study was designed to make it highly likely that the measured concentrations obtained from the study would be greater than any real exposure concentrations potentially experienced by residents who might also conduct such activities anywhere on the site. Thus, simulations were conducted at two undisturbed locations that exhibit among the highest levels of ACM contamination visually observed anywhere at the North Ridge Estates site. The study was also conducted during the driest time of year at Klamath Falls.

Data Quality

The quality of the data collected during the EPA study was also evaluated by looking at blanks and replicate analyses (among other things). Results of this evaluation suggest that the manner in which at least some of the blank samples were analyzed may not be sufficient to eliminate potential concerns associated with laboratory or filter contamination. However, there is no direct evidence that such contamination has in fact tainted the project. Thus, this concern was primarily considered to contribute to the overall uncertainty of the project data and no adjustments to the data were made. This type of uncertainty suggests an increased chance that exposures and risks are over-estimated.

Interpretation of EPA Study Results

Risk estimates derived based on the exposure concentrations measured during the EPA study all fall into the range that is potentially considered acceptable by EPA on a permanent basis, when site-specific conditions are addressed. Thus, if (as intended) they truly represent upper bound estimates of any actual risks that might occur when residents conduct similar activities over other portions of the site, there is no indication of an imminent hazard that might otherwise suggest that the risks from these activities are not at least acceptable in the short term.

The above conclusions are consistent with the conclusions indicated in the Preliminary Soil Report. This is not surprising as the largest of the risk estimates modeled in that report are comparable in magnitude to those derived from the EPA study. However, any formal comparison between such estimates requires explicit consideration both of the conditions under which measured and modeled estimates were derived and the differences in the manner in which conservatism is built into each estimate. Because such a comparison can provide an improved indication of the nature of potential exposures and their attendant risks at the North Ridge Estates Site, a more detailed comparison was completed, subject to the limitations of the available data, and the results are separately presented for child's play and rototilling below.

Note that, although weed trimming was evaluated during the EPA study, it was not modeled in the Preliminary Soil Report. Thus, weed trimming is not further addressed.

Comparing Measured and Modeled Exposure

When exposure concentrations are modeled for child's play using inputs that represent the actual field conditions of the simulations conducted during the EPA study, modeled exposure estimates are substantially smaller than measured estimates. Therefore, the source of this discrepancy was evaluated and found to be primarily due to the drying of soil during actual play in the manner conducted during the simulation.

Given the above, a new, optimized model for child's play was developed incorporating a refined moisture content term that was reconciled with the measurements from the EPA study. The other input factors representing field conditions were also modified to make them conservative for the site as a whole (rather than specific to the conditions encountered during the EPA study). This new model was then applied as described below to develop improved, bounding estimates of exposure and risk for the site.

When exposure concentrations are modeled for rototilling using inputs that represent the actual field conditions of the simulations conducted during the EPA study, modeled exposure estimates are substantially larger than measured estimates. Therefore, the cause of such over-estimation was evaluated and found to be primarily due to the dispersion term in the model.

Note that the finding that the dispersion term is overly-conservative for rototilling is consistent with the discussion of this model in the Preliminary Soil Report. The report indicates that the model was in fact designed to estimate exposure to individuals *following in the plume* of the person who was rototilling (rather than the person conducting the rototilling themselves). This was done because (1) the modifications required to model direct exposure to the rototiller were too complex to consider at the time the Preliminary Soil Report was written and (2) the exposures estimated with the model as configured were known to bound such exposures in any case.

Importantly, the use of an overly-conservative dispersion term was also incorporated into many of the other models applied in the Preliminary Soil Report (with the notable exception of the model used to assess both child's play and gardening). Thus, downward adjustments of the bounding risks estimated for the other pathways modeled may also be warranted.

Given the above, a new, optimized model for rototilling was developed by incorporating a refined dispersion term that was reconciled with the measurements from the EPA study. The other input factors representing field conditions were also modified to make them conservative for the site as a whole (rather than specific to the conditions encountered during the EPA study). This new model was then applied as described below to develop improved, bounding estimates of exposure and risk for the site.

Improved, Bounding Estimates of Exposure and Risk

The optimized models developed for child's play and rototilling were used in this report to provide improved, bounding estimates of exposure and risk. Such exposures and risks were estimated separately for exposure to chrysotile and amphibole asbestos.

Chrysotile-related risks

In all cases, estimates derived using the optimum models are greater (more conservative) than corresponding estimates based on the measured exposures from the EPA study. For child's play, the new estimates are also somewhat larger than those presented in the Preliminary Soil Report. That is because the optimized models better account for our improved understanding of uncertainty at the site.

However, although the risk estimates derived using the optimized models in this report are somewhat larger than those derived directly from the EPA simulation study or (for child's play) from those reported in the Preliminary Soil Report, this does not mean that actual risks have changed. In fact, the best estimates for actual risks have not changed. Rather, what has been done is to increase the conservatism of the bounding risk estimates to better account for uncertainty.

With an improved understanding of the site that will come with additional characterization, it is likely that risk estimates will be reduced, as any actual risks are highly likely to be lower than those currently estimated. Nevertheless, given the current uncertainty associated with conditions at the site, (with the possible exception of a small, downward adjustment discussed in the body of this report), the risk estimates presented in this report are the best bounding estimates that can currently be developed.

The chrysotile-related risk estimates presented in this report can be interpreted as follows. First, risks attributable to the child's play scenario are substantially greater than those estimated for rototilling. Moreover, as indicated above, the other residential scenarios modeled in the Preliminary Soil Report likely over-estimate risk in a manner entirely analogous to that described for rototilling. Therefore, it is expected that any short-term risks estimated from the optimized model for child's play in this report bound risks for rototilling and the other residential pathways addressed in the Preliminary Soil Report, with one exception. The one exception (the pathway for handling of ACM) is addressed directly in the recommendations section of the Preliminary Soil Report.

Given the above, the chrysotile-related risks estimated in this report do not suggest the presence of an imminent hazard attributable to exposure to chrysotile at the site. Thus, as indicated in the Preliminary Soil report, there is time to study and remediate the site.

Amphibole-related risks

Prior to estimating amphibole asbestos-related risks, the occurrence of amphibole asbestos at the site was evaluated by considering the results from all sampling and analysis campaigns that have recently been conducted at the North Ridge Estates Site. Results indicate that amphibole asbestos is only rarely encountered. In fact, when the single hot spot sample that was collected from a hole in a foundation is omitted from the data set, amphibole asbestos structures represent only approximately 3% of the asbestos structures that have been observed to date. Moreover, the lack of any defined pattern in the locations where the isolated amphibole asbestos structures have been detected suggests a broadly dispersed, very low level of contamination.

Note that the hot spot sample collected from a hole in a foundation was likely collected from a location where steam pipe originally entered the house. Such a location is therefore highly likely to exhibit concentrations of amphibole asbestos. This sample was therefore omitted from this part of the evaluation because it clearly does not represent general or typical conditions at the site.

Regarding amphibole asbestos-related risks, bounding estimates for exposures and their attendant risks were derived using the optimized models described above. These are substantially higher than the risks estimated for chrysotile asbestos. In fact, even though they represent bounding estimates, so that actual risks are likely to be substantially lower, they fall into a range of potential concern. Even the one-year exposure estimates do not compare favorably to the EPA risk range.

These results suggest that immediate attention may be needed at the North Ridge Estates Site. Although, such concerns are somewhat mitigated by observations that:

- the amphibole asbestos-related risks presented in this report are based on upper bound estimates that are essentially derived from the observation of a single structure in a soil sample collected during the special EPA study;
- the QC checks conducted on the EPA study data are not sufficient to eliminate concerns that some of the data may have been contaminated; and
- additional factors discussed in the report suggest that the bounding risk estimates presented for both chrysotile and amphibole asbestos can be reduced by at least a factor of three.

Conclusions and Recommendations

Given the bounding exposure and risk estimates provided in the report, for now, it would be prudent to limit intimate contact with local soils (especially children playing in such soils). Although bounding risks estimated for exposure to chrysotile do not suggest the existence of an imminent hazard, the bounding risks estimated for exposure to amphibole asbestos, suggest otherwise. Despite the mitigating factors that have been identified for the bounding risks estimated for amphibole asbestos, prudence dictates that residential activities involving physical proximity to the soil while it is disturbed (such as when children play in dirt or adults garden) should be curtailed until either the magnitude of such risks can be better characterized and shown to be lower than the bounding estimates suggest or site mitigation is completed.

At the same time, it needs to be recognized that the bounding risk estimates developed for amphibole asbestos are based on upper confidence limit estimates derived from the detection of a total of six structures among all of the samples collected at the site. Moreover, three of these six structures were observed in a single sample that appears to have QC problems and was prepared using a procedure for which there is no established protocol to guide interpretation of the results. Therefore, it is highly likely that the bounding estimates provided in this document, particularly for amphibole asbestos, are extremely conservative relative to any actual exposures and risks that may occur at the site. Thus, while prudence dictates caution, more data will clearly be required before any definitive conclusions can be drawn regarding exposure and risk at the site.

Importantly, the above recommendations should be considered in addition to (rather than supplanting) the recommendations provided in the Preliminary Soil Report.

2. INTRODUCTION

This report presents an evaluation of the results from a special study by the U.S. Environmental Protection Agency (EPA) conducted at the North Ridge Estates Site in Klamath Falls, Oregon on July 20-22, 2004. Exposure and risk estimates extrapolated from the EPA study are also compared with exposure and risk estimates presented in the recent, Preliminary Soil Report for the site (Berman 2004) with the potential limitations of such comparisons also addressed.

Comparing results between the EPA study and the Preliminary Soil Report provides an improved understanding of the nature of uncertainties associated with projecting exposures and their attendant risks at the site. Consequently, by reconciling measured and modeled results from these two studies, a revised set of bounding exposure and risk estimates are developed and presented for the site. Among other things, the revised estimates better account for contributions from amphibole asbestos, which has occasionally been observed in a small number of samples from several of the various sampling campaigns that have been conducted at the site. Thus, the occurrence of amphibole asbestos among such data sets is also reviewed.

During the EPA special study, contractors (in full protective gear) conducted simulations of a selected set of dust generating activities performed by residents at the site. The objective was to obtain measurements of airborne concentrations of asbestos that would bound exposures and the attendant risks potentially experienced by residents while conducting the activities simulated.

Because exposures and risks attendant to similar activities were modeled in the Preliminary Soil Report (Berman 2004), a comparison between measured and modeled results is useful. For such comparisons to be valid, however, the conditions under which the simulations were conducted must be properly correlated with the conditions modeled. Many (but not all) of the factors required to adequately correlate conditions were determined during the EPA study, which unfortunately limits the degree to which measured and modeled results can be compared. This is because comparison with modeled results was not a primary design objective of the EPA study.

Comparisons between the EPA study and soil report results must also be made with care because the two studies do not provide the same kinds of estimates. While the current EPA study and the earlier soil report both provide conservative estimates of risk, the EPA simulations provide conservative estimates that are only single "snap-shots" in time. In contrast, the exposure and risk estimates from the soil report represent conservative estimates of long-term averages contributed by the various activities. Thus, even if the estimates from the EPA study are adjusted for duration and frequency of exposure, this still ignores the effects of the time-variation of other inputs to the exposure and risk estimates.

To illustrate the above, time adjustments to the EPA study results would still incorporate an assumption that the moisture content, wind speed, or relative humidity observed during the simulations persist throughout the year. Moreover, when evaluating the simulations, it is important to account for the uncertainty in the measurements, a factor that is not applicable to the models (which, in turn, address other sources of uncertainty). Thus, the manner in which conservatism is built into each estimate and the degree to which each estimate is conservative are not directly comparable. Such limitations need to be addressed as part of any formal comparison between measured and modeled results.

Given the above, comparisons between measured and modeled results are conducted to the degree that the available data support. Using adjusted models that are reconciled with the exposure concentrations observed during the EPA study, a revised set of preliminary exposure and risk estimates are then estimated for the site.

3. BACKGROUND

To facilitate review of this document, asbestos is defined and the health effects attributable to asbestos exposure are briefly discussed below. A summary of considerations addressed in association with the measurement of asbestos is also presented.

3.1. The Definition of Asbestos

As indicated in Berman and Crump (2001), asbestos is a term used to describe the fibrous habit of a family of hydrated metal silicate minerals. The most widely accepted definition of asbestos includes the fibrous habits of six of these minerals (IARC 1977). The most common type of asbestos is chrysotile, which is the fibrous habit of the mineral serpentine. The other five asbestos minerals are all amphiboles (i.e. all partially hydrolyzed, magnesium silicates). These are: fibrous reibeckite (crocidolite), fibrous grunerite (amosite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos.

All six of the minerals whose fibrous habits are termed asbestos occur most commonly in non-fibrous, massive habits. While unique names have been assigned to the asbestiform varieties of three of the six minerals (i.e. chrysotile and two of the amphiboles, which are noted parenthetically above) to distinguish them from their massive forms, such nomenclature has not been developed for anthophyllite, tremolite, or actinolite. Therefore, when discussing these latter three minerals, it is important to specify whether a massive habit of the mineral or the fibrous (asbestiform) habit is intended.

3.2. The Health Effects Attributable to Asbestos Exposure

When disturbed by natural forces or human activities, asbestos can release microscopic fibers and more complex structures (e.g. bundles and clusters)[1] into the air and many of these structures are respirable. It is generally accepted that inhalation of such asbestos structures can lead to a range of adverse health-effects including, primarily: asbestosis, lung cancer, and mesothelioma (see, for example, Berman and Crump 2001).

Asbestosis, a chronic, degenerative lung disease, has been documented among asbestos workers from a wide variety of industries. However, the disease is expected to be associated only with the higher levels of exposure commonly found in workplace settings and does not typically result from environmental

[1] For concise definitions of respirable asbestos structures, see ISO (1995).

asbestos exposure[2]. Therefore, asbestosis is not addressed further in this document.

The types of lung cancers that have been attributed to asbestos exposure are similar to those attributed to smoking. Further, simultaneous exposure to asbestos and cigarette smoke tends to have a multiplicative effect on the risk of developing lung cancer (Berman and Crump 2001).

Mesothelioma is a rare cancer of the membranes that line the pleural cavity (which surrounds the heart and lungs) and the peritoneal cavity (i.e. the gut). Although there is some evidence of a low background incidence of spontaneous mesotheliomas in the general population, this cancer has been associated almost exclusively with exposure to fibrous substances (HEI-AR 1991). In most cases, this means exposure to asbestos. In rare cases, however, exposure to other fibrous substances has also been linked to the induction of mesothelioma. For example, erionite (a fibrous zeolite mineral that occurs in some volcanic tuffs) has been established as the causative agent for the high rate of mesothelioma observed in some villages in Turkey (Baris 1987).

Gastrointestinal cancers and cancers of other organs (e.g. larynx, kidney, and ovaries) have also been linked with asbestos exposure in some studies. However, such associations are not as compelling as those for the primary health effects listed above and the potential risks from asbestos exposure associated with these other cancers are much lower (see, for example, Berman and Crump 2001). Consequently, by addressing the more substantial asbestos-related risks associated with lung cancer and mesothelioma, the much more moderate risks potentially associated with cancers at other sites are also addressed by default. Therefore, the risks addressed in this document are focused on lung cancer and mesothelioma.

3.3. Considerations Associated with Asbestos Measurements

When air samples are analyzed for the determination of asbestos (see, for example, ISO 1995 or NIOSH 1989a), results are reported in terms of the number of structures (of a selected range of sizes) per unit volume of air. As long as an appropriate range of asbestos structure sizes are selected for determination, such structure number concentrations are generally considered to predict risk (see, for example, Berman and Crump 2001 or IRIS 1988). In contrast to most other hazardous materials, mass concentrations of asbestos

2 It should be emphasized that this site differs in two critical ways from the site in Libby, MT where asbestosis has been observed among the local population (U.S.EPA 2000a, 2001). First, exposure at North Ridge is primarily to chrysotile and none of the fibrous winchite-richterite (sometimes called soda tremolite) found at Libby has been found or is expected to be found at North Ridge. Second, it is currently believed that substantial exposures that are much larger than typical for residential scenarios may have occurred for at least a subset of the population at Libby (U.S.EPA 2001).

(e.g. the number of grams of asbestos per unit volume of air) have been shown to predict neither structure number concentrations nor any associated risk (Berman and Crump 2001).

In this report, asbestos-related risks are estimated using each of two procedures that each requires exposure concentrations to be reported in terms of a specific size range of structures. For the procedure currently employed by EPA, exposures are reported in terms of concentrations of 7402 fibers and time-averaged exposures are multiplied by the unit risk factor (URF) recommended in IRIS (1988) to estimate risk. 7402 fibers are asbestos structures longer than 5 µm, thicker than 0.25 µm, and that exhibit an aspect (length to width) ratio greater than 3. These structures are termed "7402 fibers" because they are the range of structures defined for counting under the "B" rules of NIOSH Method 7402 (NIOSH 1989a). These are also the counts of structures that are designed to mimic the counts of asbestos fibers observed by optical microscopy, such as by NIOSH Method 7400 (NIOSH 1989b).

To better assure adequate protection of public health, risks are also estimated in this report using a second procedure, which was defined by Berman and Crump (2001). For this procedure, exposures are reported in terms of "protocol" structures and time-averaged exposures are multiplied by an appropriately selected URF that is matched for asbestos size and type. Protocol structures are asbestos structures longer than 5 µm and thinner than 0.5 µm. The selected URF varies as a function of the fraction of protocol structures that are longer than 10 µm and also varies depending on whether the type of asbestos is chrysotile or one of the amphiboles. Among the biggest differences between this approach and the approach currently employed by EPA is that the protocol by Berman and Crump incorporates consideration of substantially greater potency (fiber-for-fiber) for amphibole asbestos types compared to chrysotile asbestos. The derivation of the URF's employed in this document is described in detail in the Preliminary Soil Report.

In the special EPA study (and other studies conducted at the North Ridge Estates Site and discussed in this report), asbestos samples are ultimately analyzed by transmission electron microscopy (TEM) using the counting rules defined in ISO Method 10312 (ISO 1995). For some of the samples, a greater range of structure sizes were included in the count than those required to assess risk (which are identified above). However, such structures are still evaluated in this report to support comparisons between concentrations exhibited by various samples. Thus, two additional size ranges of asbestos structures are defined here because they are discussed in the text of this report:

- Long ISO structures represent the total of all asbestos structures longer than 5 µm that exhibit an aspect ratio greater than 3. This range of structures includes both 7402 structures and protocol structures; and

- Short ISO structures represent the total of all asbestos structures of length equal to or less than 5 μm that also exhibit an aspect ratio greater than 3.

The latter set of structures is not generally considered to be in the range of structures that contribute to carcinogenicity (see, for example, Berman and Crump 2001). Moreover, due to the manner in which risks are estimated based on the counts of longer structures, any (small) contribution to risk that might otherwise be associated with exposure to these short structures would be included by default within the estimates derived from counts of longer structures. Therefore, these structures are not addressed further with regard to their potential to contribute to risk.

4. SPECIAL EPA STUDY DESIGN

Although the details of the design of the EPA study have been provided elsewhere (E and E 2004), a summary is presented here to provide the framework within which study results can be interpreted.

Three activities were selected for simulation:

- *a child-playing in dirt, during which a gallon bucket was repeatedly filled and* emptied;
- weed trimming using a nylon cord weed trimmer; and
- rototilling using a commercially available rototiller.

Multiple trials (up to four) were conducted for each activity in an attempt to determine both a conservative mean for the simulations (under the specific conditions evaluated) and the variation about the mean. The studies were also designed in a manner that attempted to control for many of the largest sources of variation, including meteorology (E and E 2004).

The EPA study was designed to make it highly likely that the measured concentrations obtained from the study would represent conservative, bounding estimates of exposure associated with the simulated activities. Thus, simulations were conducted at two undisturbed locations[3] that exhibit among the highest levels of ACM contamination visually observed anywhere at the North Ridge Estates site[4]. The selected locations, which are on an unoccupied parcel, were not included in the most recent surficial cleanup of the site (PBS 2004).

[3] One location, a 5 ft by 5 ft area, was used for the child's play scenario. A substantially larger second location (51 ft by 102 ft) was used for both the weed trimming and rototilling scenarios.

[4] Whether the visual cues employed in the field to select conservative "hot spots" of bulk asbestos concentrations indeed correlate with measured concentrations is also addressed in this report.

However, the locations appear to have been included in the previous surficial cleanup conducted by Malot (U.S.EPA 2003, Appendix C). The study was also conducted during the driest time of year at Klamath Falls, although there were reports of at least some precipitation during the night before the study began (J. Wroble, personal communication).

During each simulation of the EPA study, a contractor performed a selected activity in a controlled manner while air samples were collected from the breathing zone of the contractor. The samples were then prepared and analyzed to determine potential exposure concentrations of asbestos in the air. Two such samples were collected during each trial of each simulated activity, but only one was analyzed. Ambient air samples were also collected at nearby stationary locations, which were either upwind or crosswind of the areas where simulations were being conducted. The ambient samples were collected over the entire 8-hour period of each of the three days during which all of the multiple trials were conducted for each of the three selected activities. All samples were analyzed using the counting and identification rules of ISO Method 10312 (for determination of asbestos following preparation by a direct transfer technique – ISO 1995).

Dust concentrations and meteorology were also monitored during each experiment. Emitted dust was monitored by an automated particle counter (The MIE PDR 1000) that provides calibrated readouts of mean respirable dust concentrations over one-minute intervals. The monitor was worn at waist height[5] by the individual conducting each simulation. Wind speed and direction, temperature, and relative humidity were also determined over one-minute intervals at an automated meteorological station setup in proximity to the study area.

Three soil samples were also collected and analyzed as part of the EPA study. The samples were intended to characterize the source material from which dust and airborne asbestos were generated during each of the simulations.

One "grab" sample was collected from the area used to conduct the child's play simulation and two composite samples were collected over the larger area where simulations for weed trimming and rototilling were conducted. To construct the composite samples, the area used for weed trimming and rototilling was divided into a three by three grid of equal-sized rectangles and a component sample was collected from a random location within each of the nine rectangles. To construct the composites, the corresponding set of component samples was then combined and homogenized in the field.

[5] Unfortunately, determination of dust concentrations at waist height (rather than at the breathing zone) severely limits the utility of correlating measured dust and asbestos concentrations.

A separate set of random locations was selected for the components used to construct each of the two composites from the weed trimming/rototilling area. Thus, these samples represent a pair of true duplicate composites in that variation between them fully incorporates spatial variability in the field. Note that, because one of these duplicate composites was also split and analyzed as a pair of duplicate splits, four soil analyses are reported from the EPA study. Duplicate splits indicate potential variability introduced by the process of sampling and analysis, but do not address spatial variability in the field.

5. SPECIAL EPA STUDY RESULTS

The asbestos air data, dust data, and asbestos soil data from the special EPA study are separately presented and discussed in this section. The quality of these data is also addressed.

5.1. Asbestos Air Data

A summary of the airborne asbestos concentrations observed during the various trials of the EPA study is provided in Table 1. In Table 1, the first column indicates the specific simulation type and the trial from which each sample was collected. The second column indicates the analytical sensitivity achieved during the analysis of each sample. The next three columns of the table indicate, respectively, the number of short protocol structures, long protocol structures, and 7402 fibers counted during each analysis. The last three columns of Table 1 indicate, respectively, estimated concentrations for total protocol structures, the fraction of protocol structures that are long, and estimated concentrations for 7402 fibers.

Note that because no 7402 fibers were detected in either of the two rototilling trials, an upper bound estimate on the observation of zero structures in these trials has been estimated and is also provided in the last column of the table. This upper bound estimate is derived as three times the pooled analytical sensitivity for the two rototilling trials. This is because a count of three represents the 95% upper confidence limit (UCL95) on a count of zero structures (assuming that structure counts are Poisson distributed) and concentrations are typically estimated as the number of observed structures multiplied by the appropriate analytical sensitivity. The analytical sensitivities are pooled over the two rototilling trials because, as can be seen in Table 1, results from the two trials are entirely consistent. Pooled analytical sensitivities are estimated as the reciprocal of the sum of the reciprocals of the analytical sensitivities for each individual trial. Thus:

$$\text{Pooled Analytical Sensitivity} = 1/[\Sigma_i(1/\text{analytical sensitivity for trial i})]$$

As indicated in Table 1, samples were analyzed from two of the four trials conducted to simulate child's play, three of the four trials conducted to simulate weed trimming, and two of the three trials conducted to simulate rototilling. In general, samples were not analyzed when they were found to be overloaded with dust, which would prohibit preparation by direct transfer. In the case of child's play, however, three of the sets of filters collected during the four trials were mounted upside down in the storage dish after their initial examination (but before final analysis). This led to fears that asbestos structures would be lost (J. Wroble, personal communication). However, given the close agreement in results between the samples from the two child's play trials that were analyzed (Table 1), this fear appears to be unwarranted.

Of the two samples analyzed for child's play, one was originally mounted correctly and the other was mounted upside down. Yet the concentrations of structures observed in the two samples vary by less than 2%. This is even smaller variation than what might be expected due to the irreducible statistical variation associated with structure counting in general.

That mixed cellulose ester (MCE) filters were used during this study (as opposed to polycarbonate filters) should also lessen (but not eliminate) the concern with loss of particles due to inversion. Unlike polycarbonate filters, particles captured on MCE filters are usually trapped within the porous webbing of the filters so that they are difficult to dislodge. In contrast, polycarbonate filters are smooth plastic sheets with microscopic holes etched into the plastic to make them porous. Thus, particles captured by these filters are usually deposited at the immediate surface and can be easily dislodged if the surface comes into contact with another surface.

As indicated in Table 1, no risk-relevant asbestos structures were detected on any of the ambient samples[6]. Based on the wind data collected from the onsite meteorology station during the simulations, the locations of the ambient samplers relative to the areas where the simulations were conducted were generally upwind or crosswind and were at least 100 ft from where activities were being simulated.

5.2. Respirable Dust Data

Dust concentrations collected during the EPA study (measured at the waist of the individual conducting each simulation) were also evaluated and results are presented in Table 2. In Table 2, the first column indicates the specific activity

[6] One short chrysotile structure (shorter than 5 μm) was observed in the ambient sample collected during child's play. However, such structures have not been formally linked to biological activity (see, for example, Berman and Crump 2001). In fact, as indicated in Berman and Crump (2001), even if such structures potentially contribute to risk, any such contribution is included by default in the risk estimates derived based on the longer structures. Thus, although they were counted in the EPA study, the concentrations of structures shorter than 5 μm are not presented in Table 1 and are not addressed further in this report.

simulated and the second column indicates the specific trial during which the dust measurements were obtained.

The third column of Table 2 indicates the mean dust concentrations observed during each trial. This was determined by averaging the individual concentration estimates for each minute of the time during which each trial of each simulation was being conducted.

The last column of Table 2 indicates the mean dust concentrations considered as potential background for each simulation. These were estimated by averaging individual concentration estimates for each minute of the time immediately before each trial was initiated and immediately after each trial was completed.

What is interesting about the dust measurements is that, while they confirm that substantial dust was generated during the simulations of child's play and of rototilling, relatively little dust was generated during weed-trimming. In fact, for all but the first trial for weed-trimming, background dust concentrations were either higher or as high as those observed during the actual trial. Thus, it appears that the dust generating potential for this pathway is limited relative to other pathways. This also complicates the interpretation of the asbestos measurements collected during weed-trimming. Nevertheless, the asbestos measurements from weed trimming are carried through the following analysis without modification.

5.3. Asbestos Soil Data

Results of the analysis of soil samples from the EPA study are presented in Table 3. In Table 3, the first two columns indicate the nature of the simulations conducted in areas from which each sample was collected and the type of sample, respectively. The identification number for each sample is presented in the third column.

The fourth and fifth columns of Table 3 indicate, respectively, the type of asbestos observed in each sample (chrysotile or amosite, a form of amphibole asbestos) and the analytical sensitivity achieved for each determination of concentration. The next three columns of the table indicate the numbers of asbestos structures observed in each sample as total protocol structures, long protocol structures (longer than 10 μm), and 7402 fibers, respectively. The last three columns of the table indicate the concentrations of protocol structures found in soil, the fraction of protocol structures longer than 10 μm, and the concentrations of 7402 fibers found in soil, respectively.

5.4. Quality Control

The quality of the data collected to characterize airborne asbestos concentrations observed during the simulations of the EPA study and to characterize the concentrations of asbestos observed in source soils was also evaluated to determine their suitability for use in supporting risk assessment.

5.4.1. Quality of air data

To evaluate the suitability of the air data, the following quality control checks were performed:

- analysis of blanks to test for sources of external contamination;
- analysis of the uniformity of the filter deposits on the air samples to evaluate the reliability of the estimated concentrations; and
- analysis of concentration estimates obtained from replicate simulations to evaluate overall variability.

Each is discussed separately below.

5.4.1.1. Blanks

Results from the analysis of blank samples analyzed in support of the special EPA study are summarized in Table 4. In Table 4, the first column indicates whether the blanks were analyzed in support of the batch of soil or air samples collected during the project. The second and third columns indicate, respectively, whether the results presented in a particular row represent those from blanks or analytical samples. The fourth column indicates the type of sample.

The fifth column of Table 4 indicates how many structures were observed on each of the blank samples. Note that two of the eight blanks reported showed detection of one structure each.

Columns 6 through 8 of Table 4 respectively provides the number of grid openings scanned during each analysis, the corresponding area of the filter scanned, and (for laboratory blanks and analytical air samples) the volume of air passed through the filter.

The ninth column of the table indicates the analytical sensitivity achieved for laboratory blanks and analytical air samples. Note that analytical sensitivities for analytical soil samples, which are reported in different units, are not indicated in the table. For the air samples, analytical sensitivity is determined as:

$$AS = N_{str}*A_f/(A_{scan}*V_{air}) \qquad (1)$$

Where:

AS is the analytical sensitivity str/L), which is the concentration equivalent to the observation of a single structure during the analysis;

N_{str} is the number of structures observed (assumed to be one when calculating the analytical sensitivity);

A_f is the area of the analytical filter (mm^2);

A_{scan} is the area of the filter actually scanned (mm^2); and

V_{air} is the volume of air passed through the analytical filter (L).

The last column of Table 4 provides estimates of the surface loading sensitivity achieved for each sample. The surface loading sensitivity, is the surface density of structures (in number of structures per mm^2 of filter) on the sample filter that would be equivalent to detection of a single structure during the indicated analysis. Surface loading sensitivity is determined as:

$$SLS = N_{str}/A_{scan} \qquad (2)$$

Where:

SLS is the surface loading sensitivity, which is the number of structures per unit area of filter equivalent to the detection of a single structure during the analysis; and

all other parameters have been previously defined.

The data presented in Table 4 suggests that the analysis of blanks during the special EPA study may not have been sufficient to entirely eliminate concerns that at least some of the asbestos observed during analysis of the samples from this study could have come from filter or laboratory contamination.

As can be seen in the top half of Table 4 (regarding the soil sampling effort), the surface loading density for blanks achieved in this part of the study was 9.9 s/mm^2. In comparison, analytical soil samples were analyzed in a manner such that the detection of a single structure would imply a surface loading of approximately 0.7 str/mm^2. This means that the surface loading sensitivity for blanks is 10 times less sensitive than that for analytical samples. Correspondingly, this means that one would have to detect a minimum of 10 structures on an analytical filter (by the procedures used to analyze the analytical filters) before even one structure would be expected to be seen if the same sample were to be analyzed by the procedures used to analyze blanks. More simply, this suggests that one would need to detect a minimum of 10 structures on an analytical filter before having reasonable confidence that at least one of those structures did not come from laboratory or filter contamination.

Because multiple blanks were analyzed in support of the soil analyses in the EPA study, it is appropriate to pool these results to establish the power of the blank analyses. Thus the pooled surface loading sensitivity for the four blank samples is estimated as the reciprocal of the sum of the reciprocals of the surface loading sensitivities for each individual blank. The resulting value is presented in Table 4 in bolded text to the right of the word, "Pooled."

So that one can be 95% confident that a structure detected on an analytical filter is actually from the sampled medium (as opposed to laboratory or filter contamination) two conditions must be satisfied:

1. no structures are detected in the blanks and

2. the surface loading observed on the analytical filter exceeds the 95% upper confidence limit (UCL95) to the surface loading sensitivity achieved for the blanks.

Because structure counts are expected to be Poisson distributed, a surface loading equal to the detection of three structures would constitute the UCL95 for the structure loading sensitivity represented by a blank sample (or pool of blank samples) in which no structures were actually detected. Thus, the UCL95 estimate for the surface loading sensitivity is presented in bold in Table 4 immediately under the pooled surface loading sensitivity for blanks. As can be seen in the upper half of the table, the UCL95 for the pooled blanks exceeds the surface loading sensitivity achieved for analytical soil samples by a factor of approximately 10. Thus, analysis of these blank samples do not appear sufficient to effectively eliminate the concern that at least some of the asbestos observed in this study may have come from laboratory or filter contamination.

Completing the same evaluation for the air samples from the EPA study that are addressed in the lower portion of Table 4, it is clear that blank analyses in this part of the study appear to be similarly limited, with one notable exception. Regarding the exception, because it is possible to determine corresponding analytical sensitivities for analytical air samples and laboratory blanks, it is also possible to assess the adequacy of laboratory blanks to test for the cleanliness of laboratory air. As can be seen in Table 4, the UCL estimate for the pooled analytical sensitivity for blanks listed in the bottom half of the table is smaller than the analytical sensitivity achieved for the project air samples analyzed during the study. This suggests that laboratory air can be adequately eliminated as a source of potential contamination in this study. However, the surface loading problem with the blanks remains.

Importantly, while the evaluation presented above suggests that the manner in which at least some of the blank samples were analyzed may not be sufficient to eliminate potential concerns associated with laboratory or filter contamination, there is no direct evidence that such contamination has in fact tainted the project. Thus, this concern should primarily be considered to contribute to the overall uncertainty of the project data. In this case, it suggests an increased chance that exposure and risk estimates are over-estimated.

It should be noted that the main reason that the above, detailed discussion of blanks has been incorporated into this report is a potential concern about the observation of amphibole structures in samples prepared and analyzed using the glove box protocol as part of this study (Section 7.3.2). While three long amphibole asbestos structures were observed in one sample prepared and analyzed by this protocol, a duplicate split of this sample that was prepared and analyzed using the elutriator method shows detection only of three, short chrysotile structures.

Given the independent types of asbestos observed in the two analyses described in the last paragraph, the disparity in the observations in these sample splits cannot be due to differences in the sensitivities of the analyses. Moreover, given the proven reliability of the elutriator method (over both this study and studies in general), the source of the amphibole structures observed in the glove box sample is open to some question. Nevertheless, to be conservative, all of these results are included without modification in the interpretation of data that follows.

5.4.1.2. Filter uniformity

When asbestos samples are collected (either from air or when soil samples are prepared by the Modified Elutriator Method, Berman and Kolk 2000), asbestos is first deposited on a filter that is then prepared for analysis by TEM. When such preparation is conducted properly, asbestos structures are deposited randomly across the sample filter and the number of structures deposited is a direct function of the concentration in the original bulk sample[7]. Consequently, the chance of encountering a structure by scanning a fixed (small) area of the filter (which is how asbestos analyses are performed) is Poisson distributed[8]. Thus,

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[7] The objective of depositing asbestos on the filter is to create a "uniform" deposit, which means that particles on the filter are randomly distributed. If the deposit is not uniform, particles will not be randomly distributed so that the chance of encountering a particle will not be the same across all areas of the filter. Thus, if the deposit is not "uniform," biases may be introduced depending on the portions of the filter that are scanned during analysis.

[8] A Poisson distribution is a mathematical function (like a normal distribution) that describes the variation (differences) that will be exhibited by repeated measurements of a sample around some central value (the mean) that represents the true number of particles (or concentration) in the sample. Due to uncertainty, multiple measurements of the same sample will never provide exactly the same result. In the case of asbestos structures spread over a surface that is scanned during a measurement, the Poisson distribution describes the probability of encountering specific numbers of structures over a fixed area of the surface, given a mean concentration over the entire surface.

repeated analyses (typically over different portions) of the same sample filter will not result in identical measurements. Rather, a distribution of structure counts will be observed (which is described by a Poisson distribution with a mean equal to the mean number of structures per unit area of the filter). For this reason, structure counts observed on different portions of the filter must be compared statistically. Thus, chi-square tests[9] (Box et al. 1978) were conducted to determine whether the deposits on particular sample filters are uniform.

Per the procedures of ISO Method 30132 (ISO 1995), three grid specimens were prepared from each air sample filter collected during the EPA study. Because the three grid specimens are prepared from broadly distributed sections of a filter, a test for the consistency of the number of structures observed on each of the three specimens of the filter constitutes a test of the uniformity of the deposit across the entire filter. When filter deposits can be shown to be uniform, confidence can be placed in extrapolating structure counts observed on the filter to the concentrations of asbestos in the original sample.

An illustration of the manner in which calculations were performed to conduct each chi-square analysis is presented in Table 5. In Table 5, grid specimen labels are presented in the first column. The second column indicates the number of structures observed on each grid specimen. The total number of structures observed across all grid specimens (which is simply the sum of the number of structures observed on each individual grid specimen) is also presented at the bottom of this column.

The third column in Table 5 indicates the number of grid openings scanned on each grid specimen (which is proportional to the area of the filter represented by the scan of each grid specimen). The total number scanned on all grid specimens combined is also presented at the bottom of this column.

What is required next for the chi-square test is to estimate the "expected" number of structures on each grid specimen. This represents the number of structures that would be encountered on the fraction of the total area (across all grid specimens) that was scanned on each particular grid specimen while assuming that structures are uniformly distributed across the total area. Thus, the expected number of structures on a particular grid specimen is calculated as the total number of structures observed (indicated at the bottom of Column 2) multiplied by the area scanned on that grid specimen (i.e. the number of grid openings indicated in Column 3) divided by the total number of grid openings scanned across all grid specimens (indicated at the bottom of Column 3). The

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9 Chi-square tests are mathematical tests that compare the variation observed among a set of measurements to the variation that is predicted by a known distribution (such as a Poisson distribution) to evaluate whether such measurements can be considered to be consistent (i.e. whether they can be considered to be measuring the same thing).

expected number of structures for each grid specimen is presented in the fifth column of Table 5.

Note that, to facilitate such a calculation, the ratio of the number of grid openings (scanned on a particular grid specimen) to the total number of grid openings scanned (across all grid specimens) is presented as a normalizing factor in Column 4. The expected number of structures is then determined simply by multiplying the total number of structures by the corresponding normalizing factor for each grid specimen.

The test statistic for the chi-square test is then calculated as indicated in the last column of Table 5. This test statistic is the sum over the five grid specimens of the square of the difference between the observed (O) and expected (E) number of structures divided by the expected number of structures for each grid specimen. A test statistic is a value calculated from data for a parameter that is known to vary in a defined manner (described by a particular, statistical distribution), as long as the contributions to such variation are random (i.e. not attributable to a systematic cause). In this case, the indicated test statistic represents the chi-square parameter of a chi-square distribution (Box et al. 1978).

The test statistic is then compared to a critical value, which is determined for a specific level of significance (chosen to be 0.05 or 5% in this document) and an appropriate number of degrees of freedom. The critical value represents the value for the parameter of a distribution that is sufficiently different from the central value (mean) of the distribution to conclude that anything more extreme (further removed from the central value) is likely due to non-random effects. Thus, when the value of a test statistic is more extreme than the critical value of the distribution, it is appropriate to conclude that other factors have contributed to the variation observed in the test statistic. The level of significance represents the fraction of the distribution that we accept as sufficiently extreme to conclude that the behavior of the test statistic is not consistent with the behavior predicted by the distribution. It is common practice to use a significance level of 5%, which means that the random chance of encountering a test statistic more extreme than the test statistic obtained is no more than 5%. Depending on the nature of the comparison being considered, however, alternate significance levels can also be appropriate.

The number of degrees of freedom (df) in this case is equal to 2, which is one less than the number of realizations (i.e. the number of grid specimens, which is three) evaluated. At 5% significance with 2 df, the critical value for the chi-square distribution is 5.99 (Box et al. 1978). Thus, because the value of the test statistic in Table 2 (0.493) is less than the critical value, we can conclude that the counts across the three specimen grids are consistent so that the deposit on the filter can be considered uniform.

Structure counts across specimen grids from every sample analyzed as part of the EPA study were subjected to a chi-square analysis in this study. Thus, results for 7 air analyses and four soil analyses are presented in Table 6.

In Table 6, the first column indicates the sample identifier and the second column indicates the sample type (soil or air) for the sample filter evaluated. The total number of asbestos structures observed in each sample is presented in the third column of the table and the critical value for the chi-square distribution appropriate for each test is presented in the fourth column. The fifth and sixth columns of the table present, respectively, the value of the test statistic evaluated for counts of total structures and whether counts of total asbestos structures across the grid specimens prepared from each indicated sample can be considered to be consistent (i.e. whether the test statistic for the chi-square analysis exceeds the selected critical value).

As can be seen in Table 6, with the exception of soil Sample No. 200, all other samples are found to exhibit structure counts across grid specimens that are found to be consistent. It is thus apparent that the distribution of structures on each sample filter is sufficiently uniform to extrapolate observed counts to asbestos concentrations in the corresponding samples and media with confidence. Regarding Sample No. 200, the test statistic exceeds the critical value by only a very small margin so that, for example, the structure counts across grid specimens from this sample can be considered consistent at the 2.5% level of significance. Moreover, failing only one out of 11 tests is within the range of the number of failures that would be expected for this number of tests by chance alone. Therefore, these results present no indication of a problem with the uniformity of filter deposits.

5.4.1.3. Replicate simulations

To evaluate reproducibility in the air data, the multiple runs of each of the activity scenarios simulated in the EPA study are considered here. Because these "replicate analyses" incorporate the broadest range of variability and uncertainty (including the variability associated with changes in environmental conditions from one run to the next), they reflect the best available data for evaluating the confidence that can be placed in the representativeness of individual simulation runs.

The data in Table 1 are used to compare exposure concentrations observed across runs within each of the simulated scenarios. Thus, for child's play, it can be seen that the exposure concentrations estimated for each of the two runs vary by no more than 2% (for protocol structure concentrations) or 7% (for 7402 structure concentrations), both of which constitutes stellar agreement. Similarly, the two rototilling runs show perfect agreement between them (i.e. identical numbers of structures at identical structure concentrations are observed).

The situation with weed trimming is somewhat more complicated. Exposure concentrations reported across the three runs vary by as much as a factor of 14. Thus, the structure counts from these runs were compared using a chi square test to check for consistency. Based on counts of protocol structures (normalized to the reciprocal of the respective analytical sensitivities), the chi-square test statistic is 17.02. Because there are three runs in this set, the number of degrees of freedom is 2 and the corresponding critical value is 5.99. Thus, the results from these runs are clearly not consistent at a 5% level of significance. In fact, given that the critical value at 0.1% significance is 13.8, there is less than a one in one thousand chance that differences as large as observed across the three weed trimming runs would occur by random variation alone.

The lack of agreement across the three runs of the weed trimming scenario suggests that some kind of systematic difference was introduced in the manner that each run was conducted. Whether this was due to a systematic difference in the way that the equipment was handled or differences in environmental conditions over the three runs cannot be determined. Based on the data presented in Table 1, something happened during the weed trimming Run No. 4 that resulted in substantially larger concentrations during this run than either of the other two runs. Nevertheless, to be conservative, the largest of the exposure concentrations observed during these runs is carried through the rest of the evaluation presented in this report.

5.4.2. Quality of soil data

In parallel with the air data, the quality of the soil data was also evaluated by:

- analysis of blanks to test for sources of external contamination;
- analysis of the uniformity of the filter deposits on the samples to evaluate the reliability of the estimated concentrations; and
- analysis of concentration estimates obtained from duplicate or replicate analyses to evaluate overall variability; and

each is discussed separately below.

5.4.2.1. Blanks

As previously indicated, results from the analysis of blank samples analyzed in support of the special EPA study are summarized in Table 4, including blanks analyzed in support of soil analyses. The format of Table 4 has also been previously described (Section 5.4.1.1).

Also as previously indicated (Section 5.4.1.1), the data presented in Table 4 suggests that the analysis of blanks during the special EPA study may not have been sufficient to entirely eliminate concerns that at least some of the asbestos observed during analysis of the samples from this study could have come from filter or laboratory contamination. This is especially true for soil data (as previously discussed).

5.4.2.2. Filter uniformity

As previously indicated (Section 5.4.1.2), when soil samples are prepared and analyzed by the Modified Elutriator Method, (Berman and Kolk 2000) for determination of asbestos (as was done to support the EPA study), asbestos is deposited on a filter that is then prepared for analysis by TEM. For these samples, the method dictates that five specimen grids be prepared from each sample filter. Thus, to assure that filter deposits are adequately uniform to support extrapolation of analytical results for estimation of concentrations in the samples analyzed, the structure counts across the specimen grids from each filter were subjected to a chi square test.

The manner in which the chi square tests were conducted is described in detail in Section 5.4.1.2. Results from these analyses are presented in Table 6.

As can be seen on the bottom of Table 6, the test statistic for Soil Sample Nos. 202, 201D, and 201 are all smaller than the critical value, which implies that the deposit on filters from these samples are all adequately uniform. The test statistic for Sample No. 200 is just slightly larger than the critical value at 5% significance but is smaller than the critical value at 2.5% significance. Therefore, especially given the discussion in Section 5.4.1.2 indicating that one failure among eleven tests (due to random chance alone) is not unexpected, the data in the table indicate that all filter deposits are adequate.

5.4.2.3. Replicate simulations

To evaluate reproducibility in the soil data, the structure counts observed across the set of samples representing a composite duplicate and duplicate split (Nos. 200, 201, and 201D) were subjected to a chi square test. Details of the manner in which such an analysis is conducted are provided in Section 5.4.1.2.

The test statistic for counts of total structures across these three samples is 0.286. The critical value for comparison across three samples (i.e. with 2 degrees of freedom at a 5% level of significance) is 5.99. Thus, because the test statistic is substantially smaller than the critical value, it is reasonable to conclude that the concentrations estimated from these three replicate samples are entirely consistent.

6. DATA INTERPRETATION

The airborne asbestos concentrations observed during the simulations in the EPA study, which are reported in Table 1, were evaluated by adjusting them to provide time-averaged exposure estimates and then converting the time-averaged exposure estimates to risk estimates. Results of this evaluation are presented in Table 7.

In Table 7, the first column indicates the type of activity evaluated. To facilitate comparison, modeling results reported in the Preliminary Soil Report are also listed in this table.

The second column of Table 7 indicates the source of the concentration estimates and the source of the duration and frequency estimates used to convert the simulation measurements to time-averaged exposure estimates. The corresponding time-factor is presented in the third column of the table. The time-factor is simply the ratio of the number of lifetime hours spent conducting a specific activity (equal to the number of hours/day*days/year*years) over the total number of hours in a lifetime (24 hours/day*365 days/year*70 years). As indicated in the table, these estimates are reproduced from Table 15 of the Preliminary Soil Report.

The fourth through sixth column of Table 7 indicates, respectively, time-averaged exposure estimates for protocol structures, the fraction of long protocol structures, and the time-averaged exposure estimates for 7402 fibers. These are determined simply by multiplying the exposure concentrations measured during (or estimated from) the data from the EPA study for the corresponding activity in each row of the table (obtained from Table 1) and the corresponding time factor listed in the same row.

In all cases, the time-averaged exposure concentrations presented in Table 7 represent upper bound estimates. These are derived either by employing the maximum of the exposure concentrations observed among the trials for each specific activity or, when specific types of structures were not detected in any trial for a particular activity, by employing an upper confidence limit (UCL) estimate on the observation of zero structures (derived as described in the footnotes of Table 1). UCL estimates are denoted in the table as "less then" the indicated concentration.

Time-averaged concentrations for the activities evaluated in the EPA study that were modeled in the Preliminary Soil Report are also indicated in Columns 4 through 6 of Table 7. These are copied from Table 19 of the soil report.

The last three columns of Table 7 indicate, respectively, the mineral types of asbestos structures measured (or modeled) and the estimated contribution to risk from each of the indicated activities, based either on concentrations of protocol structures or concentrations of 7402 fibers. For protocol structure concentrations, risks are estimated simply by multiplying the reported protocol structure concentration and the appropriate unit risk factor (URF) selected from the bottom of Table 7. The appropriate URF is the one that matches the type of asbestos and the fraction of long structures among protocol structures. For 7402 fibers, risks are estimated as the product of the concentration of fibers and the EPA URF, also listed at the bottom of the table.

As can be seen in Table 7, risk estimates derived from the EPA study range between 8.E-7 (eight in ten million) and 9.E-5 (nine in one-hundred thousand). These are derived based on exposure concentrations actually measured while the indicated activities were being conducted in the field. Thus, if (as intended) they truly represent upper bound estimates of any actual risks that might occur when residents conduct similar activities over other portions of the site, such results suggest that long-term risks fall within the range of risks that are potentially acceptable to EPA on a permanent basis. Moreover, there is no indication of any imminent hazard that might otherwise suggest that the risks from these activities are not at least acceptable in the short term.

The above conclusions are consistent with the conclusions indicated in the Preliminary Soil Report. This is not surprising as the largest of the risk estimates modeled in that report (which are also presented in Table 7 of this report[10]) are comparable in magnitude to those derived from the EPA study. As previously indicated, however, any formal comparison between such estimates would require explicit consideration both of the conditions under which measured and modeled estimates were derived and the differences in the manner in which conservatism is built into each estimate. Differences in the degree to which each estimate is conservative also need to be addressed. Because such a comparison can provide an improved indication of the nature of potential exposures and their attendant risks at the North Ridge Estates Site, a more detailed comparison was completed, subject to the limitations of the available data, and the results are presented below.

7. DETAILED COMPARISON BETWEEN EXPOSURE MEASUREMENT AND MODELING

Although the EPA study was not designed to support formal evaluation or validation of the exposure and risk modeling being conducted at the site, enough data were collected to allow a more detailed comparison than presented above. However, because weed trimming was not included in the original modeling for the site, the remainder of this discussion focuses on child's play and rototilling.

10 Note that weed-trimming was not originally modeled because it was not expected to drive risk (as the results of the EPA study appear to confirm).

As previously indicated, to better compare the modeling effort with the results from the EPA study, it is first necessary to characterize the conditions under which the observed exposure concentrations were generated during the EPA study so that potentially comparable exposures can then be modeled using the procedures applied in the Preliminary Soil Report. Estimates are required for each of the input parameters that are incorporated into each model.

Detailed descriptions of the models employed for child's play (U.S.EPA 2002) and rototilling (Cowherd et al. 1974) are provided in the Preliminary Soil Report, which include identification of the input parameters for each model. With two exceptions, the list of the input parameters required for modeling child's play and rototilling are listed across the top of the left half of Table 8. These include: wind velocity, moisture content, silt content, mass handling rate, vehicle speed, width of dispersion box, mixing height of dispersion box, and the concentrations of asbestos in source soils. Values for the two input parameters not listed in the table (the particle size multiplier and the Thornswaite PE index) are set equal to the literature values recommended for these parameters (0.35 and 32, respectively), as described in the Preliminary Soil Report. To facilitate comparison, Table 8 presents both the exposure concentrations measured during the EPA study and corresponding modeled estimates.

In Table 8, the first three columns indicate, respectively, the scenario being evaluated (child's play or rototilling), the data type (measured or modeled), and the set of conditions assumed for the modeled exposures (actual field conditions or conditions modified in the manner indicated). The next seven columns indicate, respectively, measured or estimated values for: wind velocity, moisture content, silt content, mass handling rate, vehicle speed, width of dispersion box, and mixing height of dispersion box.

The 11th through 13th columns of Table 8 indicate, respectively, the concentration of protocol structures in soils, the fraction of protocol structures longer than 10 μm, and the concentration of 7402 fibers in soils. These represent the observed (or estimated) concentrations of asbestos in source materials from which emissions occur.

The last three columns of Table 8 provide measured or modeled exposure point concentrations. These are indicated, respectively, as concentrations of protocol structures, the fraction of protocol structures longer than 10 μm, and the concentrations of 7402 fibers. The measured values are all reproduced from Table 1.

As can be seen, Table 8 is divided into two main blocks. Results of the evaluation of the child's play scenario are presented in the upper block of the table and results for the rototilling scenario are presented in the lower block. Within each block, the first (shaded) row indicates values for parameters measured during the simulations of the EPA study. The measured values reported in this table for asbestos concentrations in soils and the airborne exposure concentrations have been previously discussed (Section 5). The sources of other input data and the resulting modeled estimates are separately described for child's play and rototilling below.

7.1. Considering Child's Play

As can be seen in Table 8, the input parameters required for the child's play model are: wind velocity, moisture content, mass handling rate, and the width and height of the dispersion box. Except for the dispersion box dimensions, values for all of these were formally determined for the period during which EPA simulated children playing in dirt.

Meteorological data collected during the simulations indicate that mean wind speed during the child's play scenario averaged 4.4 m/s (9.8 mph). Also during the study, a single soil sample (collected as a continuous core from 0 to 8 inches in depth) was analyzed to determine the moisture content of the soil during the simulations. This was reported as 4% (W. Mehnert, personal communication).

The mass handling rate for the child's play scenario simulated during the EPA study was also controlled. During the simulation of this scenario, the EPA contractor conducting the simulated activity repeatedly filled and emptied a one-gallon bucket every 5 minutes. Assuming a soil density of 2 g/cm^3, a gallon of soil has a mass of 7.6 kg (17 lbs). Because the bucket was filled and emptied once every 5 minutes, this is equivalent to handling 12 gallons of material every hour, which is equivalent to 7.6 x 12 = 91.2 kg/hr or 0.091 Mg/hr. Finally, because the bucket was both filled (loaded) and emptied (dumped), each gallon of soil should be considered to have been handled twice, giving a final mass handling rate of 0.18 Mg/hr.

The width and mixing height of the dispersion box employed for the child's play scenario are 0.5 m for each and the justification for these dimensions has previously been provided in the Preliminary Soil Report.

The inputs indicated above describe the conditions under which the EPA simulated child's play. The asbestos concentrations in the soils disturbed by child's play during the EPA study are also presented in Table 8: 120 protocol structures per microgram of respirable dust (str/μg_{PM10}) and 15 str/μg_{PM10} for 7402 fibers, respectively, for the two ranges potentially representing carcinogenic structures (Section 3.3). These values are reproduced from Table 3.

As indicated in Table 1, airborne asbestos concentrations determined at the breathing zone of the EPA contractor simulating child's play were observed to be 0.0088 (8.8E-02) str/cm^3 for protocol structures and 0.015 (1.5E-02) str/cm^3 for 7402 fibers, respectively. To compare these concentrations to concentrations modeled using the approach employed in the Preliminary Soil Report, the values described above for the input parameters (representing conditions under which the EPA simulations were conducted) were input into the child's play model and the output concentrations recorded. Results are indicated in the row of the first block in Table 8 labeled as "Actual Field Conditions." As can be seen in this row, modeled exposure concentrations derived using these inputs values are 0.00028 (2.8E-03) str/cm^3 for protocol structures and 0.000036 (3.6E-04) str/cm^3 for 7402 fibers.

Comparing measured and modeled airborne exposure concentrations for child's play in Table 8, it is apparent that the modeled values are between factors of approximately 30 and 40 too small. Therefore, the source of this discrepancy needs to be evaluated[11].

After careful consideration while viewing the video tape of the child's play scenario, the source of the discrepancy between measured and modeled results is apparent. It appears to be primarily due to the drying of soil during actual play in the manner conducted during the simulation[12].

The moisture content term of the original loading and dumping model (U.S.EPA 2002), is intended to represent the mean moisture content of the volume of material handled during the operation. Based on the moisture content measurement, the starting moisture content of the soil was probably close to 4%. However, it is clear that soil handled in the manner simulated comes into close, intimate contact with the air when disturbed. Moreover, meteorological measurements obtained during the child's play simulation (W. Mehnert, personal communication) indicate that the relative humidity averaged less than 37% for one of the trials and less than 43% for the other trial. These are both sufficiently

[11] Both the simulation measurements and the modeled values are intended to provide conservative estimates of exposure. However, the simluations were intended to approximate exposure during worst-case conditions, which may yield exposures that are two or three times greater than those representative of year-round averages and it is these year-round average exposures that the models are intended to bound. Thus, as long as modeled exposure estimates are no smaller than one-half to one-third of such simulation results, they should be considered to be adequately conservative. However, the variation between measured and modeled results for child's play is larger than this and is therefore further addressed.

[12] Documentation for the child's play model also indicates that, silt content was not introduced as a parameter in the model because results from field studies were too variable to determine an appropriate functional relationship (U.S.EPA 1997, 2000b). Nevertheless, emissions are expected to increase with increasing silt content. The documentation also indicates that the existing model was fit to data from sites with silt contents up to 19% and that applying the model to sites with greater silt contents results in increased uncertainty. Thus, given that soils in the area where simulations were conducted exhibit a silt content of 34% (which is substantially higher than 19%), it is possible that at least some of the observed differences between modeled and measured estimates is attributable to the high silt content of site soils. However, adjusting the moisture content term as described above, adequately addresses this issue as well.

low to promote rapid drying. Therefore, especially considering that the soil is both loaded and dumped (so that it is aerated twice), it is expected that substantial drying occurs and that the moisture content term in the model needs to be adjusted accordingly[13].

In the row of the top block of Table 8 labeled "Adjusted for Moisture Content," the model is adjusted to account for the effects of soil drying. As can be seen in the fifth column of this row, the input value for moisture content has been lowered to 0.3%. The consequent effect on the modeled exposure estimates can be seen in the last three columns of the table. The new modeled estimates for asbestos exposure concentrations are: 0.11 (1.1E-01) str/cm^3 for protocol structures and 0.013 (1.3E-02) str/cm^3 for 7402 structures. Both of these values agree well with (are within 20% of) the exposure concentrations observed during the EPA simulation studies.

Because modeled exposures are intended to represent conservative estimates of long-term, average exposure (as opposed to a single snap-shot in time), the model is also adjusted for wind. Wind speeds observed on the day that the child's play simulations were conducted were about 50% higher than annual average wind speeds. Thus, to better represent long-term conditions, the input value to the model for the wind speed is adjusted to the value representing long-term average conditions. Results are presented in the row of Table 8 labeled, "Adjustment for Mean Wind."

So that the reconciled model provides bounding estimates for the exposures potentially experienced by residents at the site, two final adjustments are also incorporated into the conditions modeled for child's play. First, the mass handling rate was rounded up to a value of 0.2 (to one significant figure) Mg/hr. Second, the maximum concentrations of protocol structures (120 s/μg_{PM10}) and 7402 fibers (70 s/μg_{PM10}) that were observed in soil components from anywhere on the site are substituted into the model.

The final, reconciled model is presented in the row of Table 8 labeled "Optimized Model." As can be seen in this row, modeled exposure concentrations derived using the Optimized Model are 0.11 (1.1E-01) str/cm^3 for protocol structures and 0.062 (6.2E-02) str/cm^3 for 7402 fibers. In both cases, these exposure estimates are somewhat larger than the exposure concentrations actually observed during the EPA simulation study.

For historical reference, the last row of the upper block of Table 8 presents the input values and modeled outputs originally presented in the Preliminary Soil

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13 The loading and dumping model (U.S.EPA 2002) is typically applied to large scale operations where the opportunity for intimate contact between disturbed soil and air (and the consequent effect of drying) is more limited. Thus, when adapted to the much smaller scale operations associated with child's play, it is not surprising that soil drying (in dry climates) becomes important.

Report. Comparing the input values presented for the Optimized Model and the Original Model, it is seen that a smaller moisture content is now incorporated (relative to the original estimate) and that a slightly larger mass handling rate is now incorporated. Also, the estimated inputs for asbestos concentrations are slightly smaller for the optimized model than for the original model. This is justified because the new estimates represent the largest concentrations of asbestos observed in the soil component of any sample collected at the site (including all "hot spot" samples) and the time frame over which the model is to be applied is considered short relative to the amount of time required for ACM to degrade so that contributions from ACM can be discounted. In contrast, the original model included contributions from ACM.

Comparing the modeled exposure concentrations indicated for the Original Model with the concentrations measured during the EPA simulation, It is apparent that the modeled estimate for protocol structures is about a factor of seven smaller than the observed concentrations while that for 7402 fibers is about a factor of three smaller. Especially given the differences in the interpretation of the measured and modeled values (see above), these differences are sufficiently small that such values should not be considered to be inconsistent. Nevertheless, a new Optimized Model is defined above by reconciling measured and modeled conditions and this new model is employed in Section 7.3 to provide improved predictions of exposure and risk associated with child's play at the site. This was done to better address our improved understanding of uncertainty that was derived from the above comparison of modeled and measured estimates.

7.2. Considering Rototilling

As can be seen in Table 8, the input parameters required for the rototilling model are: wind velocity, silt content, vehicle speed, and the width and height of the dispersion box. Except for the dispersion box dimensions, values for all of these were formally determined for the period during which EPA simulated rototilling.

As previously indicated, meteorological data collected during the simulation studies indicate that mean wind speed during the rototilling scenario averaged 4.4 m/s (9.8 mph). Also during the study, a single soil sample was analyzed to determine the silt content of the soil at the location where the simulations were being conducted. This was reported as 34% (W. Mehnert, personal communication).

The vehicle speed with which the rototiller was advanced during the simulation was estimated from the video tape of the exercise. Including the frequent stops in the effort, the mean vehicle speed was estimated to be 1 mph (1.6 kph).

The width and mixing height of the dispersion box originally employed for the rototilling scenario were 3 m and 1.8 m, respectively, and the justification for these dimensions were provided in the Preliminary Soil Report.

The inputs indicated above describe the conditions under which the EPA simulated rototilling. The asbestos concentrations in the soils disturbed by rototilling during the EPA study are also presented in Table 8: 46 protocol structures per microgram of respirable dust (str/μg_{PM10}) and 19 str/μg_{PM10} for 7402 fibers, respectively, for the two ranges potentially representing carcinogenic structures (Section 3.3). These are reproduced from Table 3.

The airborne asbestos concentrations determined at the breathing zone of the EPA contractor simulating rototilling was observed to be 0.013 (1.3E-02) str/cm^3 for protocol structures, which is reproduced in Table 8 from Table 1. Because (as previously indicated) there were no 7402 fibers observed, an upper bound estimate was derived as described in the footnotes to Table 1. Thus, the exposure concentration of 7402 fibers attendant to the rototilling simulation is less than 0.005 (5.0E-03) str/cm^3.

To compare the observed concentrations to concentrations modeled using the approach employed in the Preliminary Soil Report, the values described above for the input parameters representing conditions under which the EPA simulations were conducted were input into the rototilling model and the output concentrations recorded. Results are indicated in the row labeled "Actual Field Conditions" in the second block (the block displaying the rototilling results) of Table 8. As can be seen in this row, modeled exposure concentrations derived using these inputs values are 0.22 (2.2E-01) str/cm^3 for protocol structures and 0.091 (9.1E-02) str/cm^3 for 7402 fibers.

Comparing measured and modeled airborne exposure concentrations for rototilling in Table 8, it is apparent that the modeled values are approximately 17 times larger than the observed values. Thus, although both the simulation measurements and the modeled values are intended to provide conservative estimates of exposure, these results demonstrate that the rototilling model can be considered to be excessively conservative. It is thus instructive to evaluate the primary source of the conservatism in this model.

Based on a careful review of the rototilling model and its adaptation and application (see the Preliminary Soil Report), it is apparent that the largest contribution to conservatism that is built into this model is likely the dispersion term. In fact, as indicated in the soil report, this model actually estimates exposure to people following immediately behind a person rototilling rather than to the individual performing the rototilling themselves. Moreover, because this effect is common to all of the residential models addressed in the Preliminary Soil Report (except for the model used to evaluate child's play, gardening, and direct handling of ACM) it is likely that all of these other models are similarly conservative. This effect is explored further below.

In the row of the bottom block of Table 8 labeled "Adjusted for Dispersion," the rototilling model is adjusted to better account for the effects of dispersion. As can be seen in the ninth column of this row, the input value for the width of the dispersion box is raised to 60 m[14]. The consequent effect on the modeled exposure estimates can be seen in the last three columns of the table. The new modeled estimates for asbestos exposure concentrations are: 0.011 (1.1E-02) str/cm^3 for protocol structures and 0.0044 (4.4E-03) str/cm^3 for 7402 fibers. Both of these values agree well with (are within 20% of) the exposure concentrations observed during the EPA simulation studies.

Because modeled exposures are intended to represent conservative estimates of long-term, average exposure (as opposed to a single snap-shot in time), the rototilling model is also adjusted for wind. Wind speeds observed on the day that the rototilling simulations were conducted were about 50% higher than annual average wind speeds. Thus, to better represent long-term conditions, the input value to the model for the wind speed is adjusted to the value representing long-term average conditions. Results are presented in the row of the rototilling block of Table 8 labeled, "Adjustment for Mean Wind."

So that the reconciled model provides bounding estimates for the exposures potentially experienced by residents at the site, three final adjustments are also incorporated into the conditions modeled for rototilling. First, the silt content is increased from 34% to 38% to reflect the highest content observed in any sample at the site. Second, the maximum concentrations of protocol structures (120 s/μg_{PM10}) and 7402 fibers (70 s/μg_{PM10}) that were observed in soil components from anywhere on the site are substituted into the model. Third, the width of the dispersion box was actually reduced somewhat below the optimum value (i.e. reduced from 60 to 30 m) to address situations in which wind conditions may be substantially more unstable than conditions experienced during the EPA simulation studies.

The final, reconciled model for rototilling is presented in the row of the rototilling block of Table 8 labeled "Optimized Model." As can be seen in this row, modeled exposure concentrations derived using the Optimized Model are 0.094 (9.4E-02) str/cm^3 for protocol structures and 0.055 (5.5E-02) for 7402 fibers. In both cases, these exposure estimates are at least seven times the exposure concentrations actually observed during the EPA simulation study.

[14] What this suggests is that, under conditions common at the site, the limited vertical dispersion requires as much air as would pass through a box that is approximately 60 meters wide to dilute it sufficiently to match the small amount of dust that actually reaches to the height of an adult nose (1.75 m) at the location of a rototiller operator relative to the position of the rototiller.

For historical reference, the last row of the lower block of Table 8 presents the input values and modeled outputs for rototilling that were originally presented in the Preliminary Soil Report (Berman 2004). Comparing the input values presented for the Optimized Model and the Original Model, it is seen that the original model assumed a higher vehicle speed, a smaller width for the dispersion box, and lower values for the estimated source concentrations of asbestos.

Comparing the modeled exposure concentrations indicated for the Original Model for rototilling with the concentrations measured during the EPA simulation, it is apparent that the modeled estimates for both protocol structures and 7402 fibers are approximately 50 times the measured concentrations. Thus, the conditions originally modeled for rototilling were extremely conservative, even relative to the conservative conditions under which the EPA simulations were conducted. Thus, the new, Optimized Model, which is defined above by reconciling measured and modeled conditions, is employed in the next section to provide improved (but still adequately conservative) predictions of exposure and risk associated with rototilling at the site.

7.3. Revised Bounding Estimates for Exposure and Risk

The optimized models for child's play and rototilling are applied in this section to provide improved bounding estimates of risk at the North Ridge Estates Site. As previously indicated, these models were derived by reconciling modeled exposure estimates (from the Preliminary Soil Report) with measured exposure concentrations (from the special EPA study).

Risks are estimated in two steps. First, time-averaged estimates of exposure are derived by multiplying the instantaneous exposure concentrations presented in Table 8 and appropriate time factors (representing the duration and frequency of exposure attendant to each of the activities addressed. Second, time-averaged exposure estimates are multiplied by appropriately matched Unit Risk Factors. The corresponding Unit Risk Factors are matched for the type and size of the asbestos structures considered (see Section 3.3).

Risks attributable to chrysotile and to amphibole asbestos are both evaluated and discussed separately below. Regarding the latter, the totality of the available site data is first evaluated to better characterize the occurrence of amphibole asbestos at the site.

7.3.1. Chrysotile-related risks

Exposure and risk estimates for chrysotile are presented in Table 9. In Table 9, Columns 1 and 2 indicate, respectively, the type of asbestos and the activity scenario addressed. The next three columns indicate, respectively, the instantaneous exposure concentrations measured or modeled for protocol structures, the fraction of such structures longer than 10 µm, and the instantaneous exposure concentrations estimated for 7402 fibers. These are reproduced from Table 8.

The time factor appropriate for each activity scenario is presented in Column 6 of Table 9. These represent the fraction of a lifetime potentially spent conducting each of the activities addressed. The values presented in the table are conservative estimates derived as described in the Preliminary Soil Report and are reproduced from Table 15 of that report.

The seventh through ninth columns of Table 9 present the time-averaged exposure concentrations measured or modeled for each of the activities presented. As previously indicated, these are derived simply by multiplying instantaneous exposure estimates (Columns 3 to 5) by the corresponding time factor (Column 6).

Columns 10, 11 , and 12 of Table 9 present, respectively, appropriately matched unit risk factors for protocol structures, an "early exposure adjustment factor," and the appropriate unit risk factor for 7402 fibers (Section 3.3). The "early exposure adjustment factor" is a factor by which the unit risk factor needs to be multiplied to account for exposures of less than lifetime duration that occur early in life. This is required because the mesothelioma risk from exposure to asbestos is not linear with time since the start of exposure. The manner in which these factors are derived is described briefly in Appendix A.

Importantly, as indicated in Appendix A, the early exposure adjustment factors for chrysotile that are appropriate for non-smokers are all less than one. Thus, because children do not smoke, the unadjusted unit risk factors employed in this document are already conservative for chrysotile-related exposures that occur during childhood. However, because adults may smoke, the early exposure adjustment factors that are presented for chrysotile in Table 9 are calculated for smokers. This therefore adds an additional degree of conservatism to the already conservative risk calculations (i.e. such factors assume that people who are exposed to asbestos begin smoking at age zero).

Risks potentially associated with exposure to chrysotile that may occur while conducting the activities evaluated in Table 9 are presented in the last three columns of the table. Thus, Columns 13 to 15 present, respectively, the (unadjusted) risks estimated based on protocol structures, the risks estimated based on protocol structures adjusted for early exposures, and the risks estimated based on 7402 fibers.

Note that, formally, the risk estimates derived for 7402 fibers, which employs the unit risk factor currently recommended by EPA (IRIS 1988), should also be adjusted for early exposures because it was derived from epidemiology data in the same manner as those employed for protocol structures (see Berman and

Crump 2001 and Berman 2004). Moreover, the same factors recommended for use with protocol structures can also be applied to the EPA values, at least for chrysotile. However, because the EPA factor does not address differences in potency between chrysotile and amphibole asbestos, the factors recommended for chrysotile should likely also be applied to the EPA unit risk factor even when risks attributable to amphibole asbestos are considered below. Adjusted risks incorporating the early exposure adjustment factor are not presented in this report for 7402 fibers, because there is currently no clear policy from EPA regarding such factors.

Chrysotile-related risks are presented in the top half of Table 9. The first three rows of the table present, respectively, risks estimated for child's play based on measured exposures (derived from the special EPA study), risks modeled using the optimized model (described in Section 7.1), and modeled risk estimates assuming one-year of exposure (beginning at age zero). The next three rows of the table present the corresponding risk estimates (derived from measured and modeled data) for rototilling. The optimized model for rototilling is described in Section 7.2. Note that the rows of Table 9 describing modeled estimates are shaded.

As can be seen from the chrysotile-related risks presented in Table 9, in all cases, estimates derived using the optimum models are greater (more conservative) than those derived from the measured data. As previously indicated, both the simulations and the modeled estimates are intended to be conservative relative to actual risks that may potentially be experienced when residents conduct the activities considered. However, conservatism is necessarily introduced into each of the two sets of estimates in a distinct manner. In both cases, this is done to account for the current lack of complete characterization of the degree of variation in conditions that may exist at the site.

Although, as indicated in Table 7, the overall manner in which conservatism was originally introduced into the modeled estimates (as presented in the Preliminary Soil Report) resulted in estimates of risk that are comparable to those estimated based on the results of the EPA simulation study, the detailed comparison of these results (presented above), suggests that the current uncertainty associated with site conditions may be somewhat greater than originally considered. Therefore the conditions modeled in the Preliminary Soil Report were further refined as described above to develop the optimized models employed in this report to assess risk. These models better account for our improved understanding of site uncertainty.

Importantly, although the risk estimates derived using the optimized models in this report are somewhat larger than those derived directly from the EPA simulation study or from those reported in the Preliminary Soil Report, this does not mean that actual risks have changed. In fact, the best estimates for actual risks have not changed. Rather, what has been done is to increase the conservatism of the bounding risk estimates to better account for uncertainty. Thus, with an improved understanding of the site that will come with additional characterization, it is likely that risk estimates will be reduced, as any actual risk are highly likely to be lower than those currently estimated. Nevertheless, given the current uncertainty associated with conditions at the site, (with the possible exception of a small, downward adjustment discussed at the end of this section), the risk estimates presented in Table 9 are the best bounding estimates that can currently be developed.

The chrysotile-related risk estimates presented in Table 9 can be interpreted as follows. First, it is clear from Table 9 that the risks attributable to the child's play scenario are substantially greater than those estimated for rototilling. Moreover, as indicated in Section 7.2 the other residential scenarios modeled in the Preliminary Soil Report likely over-estimate risk in a manner entirely analogous to that described for rototilling. Therefore, it is expected that any short-term risks estimated from the optimized model for child's play in this report bound risks for rototilling and the other residential pathways addressed in the Preliminary Soil Report (except the pathway for handling of ACM)[15].

Coupled with the above, the observation that the conservative risks estimated for child's play in Table 9 only slightly exceed 1×10^{-4} (one in ten thousand) does not suggest the presence of an imminent hazard attributable to exposure to chrysotile at the site. Moreover, risks estimated for one-year exposures at the site fall well within the range of 1×10^{-4} to 1×10^{-6} (one in ten thousand to one in one million) that is potentially considered acceptable by EPA on a permanent basis.

Note, when evaluating the risks estimated for child's play that are presented in Table 9, among other conservative factors, it should be remembered that these are based on duration and frequency estimates representing the national, upper 95th percentile estimates of the amount of time that children spend outdoors and that it is assumed in the construction of these estimates that children spend 100% of that time conducting the single, specific activity modeled. It is also assumed that the hot, dry (conservative) conditions observed during the EPA simulation of this activity persist throughout the year.

Given that children spending even a third of the total time that they spend outdoors conducting this singular activity would be exceptional and that colder (more humid) and moist conditions persist for at least half of the year, it is likely that the bounding exposure and risk estimates presented in Table 9 are overly conservative by at least a factor of three and potentially more. Thus, it may be considered reasonable to lower the bounding chrysotile-related risk estimates for the longer-term exposures presented in the table 9 so that they are no more than

[15] For periods longer than 10 years, the child's play model would need to be extended to address the combined gardening and child's play scenario.

approximately one in ten thousand. Nevertheless, the complete range of conservative assumptions and factors were incorporated into these estimates to fully address our improved understanding of uncertainty and thus assure that the chance that any actual risks might be greater than those estimated would be remote.

7.3.2. Amphibole asbestos-related risks

To better estimate source concentrations of amphibole asbestos, the occurrence of these structures across all of the sampling data sets obtained from the site over the last two years is first evaluated. Results are summarized in Table 10.

7.3.2.1. The occurrence of amphibole asbestos at the North Ridge Estates Site

In Table 10, the first, second and third columns respectively indicate the type of sample included in each data set, the identity of the specific data set, and the type of asbestos structures considered. For samples in which amphibole asbestos was detected, a code is given in the fourth column of the table indicating the location from which the sample was collected. The location codes correspond to the letter codes assigned to occupied parcels in the summary air report developed for the site (Berman 2003).

Columns 5 and 6 of Table 10 indicate, respectively, the number of samples in each data set in which the indicated type of asbestos was observed and (for soil samples exhibiting detectable amphibole asbestos) the fraction of ACM observed in the sample. The remaining five columns of the table respectively indicate the number of short protocol structures, the number of long protocol structures, the number of 7402 fibers, the number of long ISO structures, and the number of short ISO structures of the indicated asbestos type that were observed among the set of samples indicated in the corresponding row. Definitions for each of these size categories of structures are provided in Section 3.3.

Note, as previously indicated, long ISO structures represent the sum of short and long protocol structures and 7402 fibers observed at the site, which are all longer than 5 μm. These represent the range of structures that potentially contribute to carcinogenicity (Section 3.3). In contrast, short ISO structures (all shorter than 5 μm) may not contribute to carcinogenicity.

As previously indicated, the data in Table 10 includes all analyses of soil and air samples from every sampling campaign conducted at the North Ridge Estates Site in the last two years[16]. The combined results from these existing data sets

[16] The only results omitted from Table 7 are those derived from the analysis of ACM, which are not relevant to the purpose of Table 7. Thus, they were omitted.

can be considered to represent general conditions at the site. Thus, a rough approximation of the relative abundance of chrysotile and amphibole asbestos structures that are potentially encountered at the site can be obtained from an evaluation of these samples. The results of such an evaluation are presented at the bottom of Table 10.

At the bottom of Table 10, the numbers of specific categories of asbestos structures are summed and the fractions (in percent) of each that are amphibole are presented. As can be seen, of the 283 long ISO structures observed in samples at the site, 15 (or 5%) are composed of amphibole asbestos. However, the majority of these were observed in the single, grab sample collected from Hot Spot No. 6 at the site. As indicated in the Preliminary Soil Report, this sample was collected from a hole in a foundation and may represent material left over from a steam pipe hookup. Therefore, this particular sample is not likely representative of general conditions at the site.

Omitting contributions from Hot Spot No. 6, of the remaining 177 (283 – 106) structures, 6 (15 – 9) or 3% are amphibole asbestos. Therefore, to a very rough approximation, this may represent the fraction of amphibole asbestos that may be contributing overall to asbestos exposures at the North Ridge Estates site.

There is no obvious pattern to the occurrence of amphibole asbestos at the site. This is illustrated in Figure 1, which depicts the locations from which each of the samples exhibiting detectable concentrations of amphibole asbestos was collected. Aside from Hot Spot No. 6 (discussed above), five other samples exhibited detectable amphibole asbestos. One amphibole asbestos structure was detected in an air sample at Location A at the northern end of the site. Three composite soil samples (collected from Parcels R, Y, and an unoccupied MBK parcel) also exhibited small numbers (one or two) of amphibole asbestos structures. Among these samples, notably, only the sample from the MBK parcel contained any amphibole asbestos structures of sufficient length to contribute to risk. Finally, the composite sample collected from Parcel L exhibited four amphibole asbestos structures when prepared using an experimental glove box procedure[17].

As can be seen in Figure 1, no grouping of any kind is apparent among the locations of the samples exhibiting detectable concentrations of amphibole asbestos. Moreover, with the exception of Hot Spot No. 6, none of these other samples exhibit sufficient numbers of amphibole structures to be statistically distinguishable from detection of zero structures. Therefore, the best interpretation of these results is that they represent detection of a low level of

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[17] This procedure was developed by Jed Januch of EPA, Region 10 (J. Januch, personal communication) and is currently being evaluated to determine its utility. However, there is currently no established procedure for quantitatively relating the results from analyses of glove box samples to exposure or risk. Nevertheless, the results from the glove box samples are included in Table 7 and Figure 1 for completeness.

amphibole contamination that may be dispersed generally throughout the site (even where amphibole has not been detected).

Importantly, although the results from the glove box analyses have been included in this discussion for completeness, as indicated in Footnote 17, there is currently no established procedure for quantitatively relating such results to exposure or risk. Moreover, the particular sample in which the amphibole structures were observed is especially difficult to interpret in that, unlike the other glove box samples, it is internally inconsistent with the results of the analysis of a duplicate split of the same sample by the Modified Elutriator Method (Berman and Kolk 2000).

While the glove box sample exhibited detectable concentrations of amphibole asbestos, no chrysotile was detected. In contrast, when a split of this sample was analyzed by the Modified Elutriator Method, only chrysotile (and no amphibole asbestos) was detected. Thus, results across the two methods appear to be inconsistent. Moreover, the inconsistency cannot be explained by differences in sensitivity because neither method consistently exhibited higher concentrations of both asbestos types. Also, the inadequacy of the blank analyses conducted along with these samples (Section 5.4.1.1) further confounds the ability to interpret the results from these analyses.

Extensive quality control has been used to confirm the performance of the Modified Elutriator Method during study of the North Ridge Estates Site (which is also consistent with findings from studies at other sites). Thus, coupled with the lack of adequate quality control conducted in association with the glove box method for studies at this site, the above observations raise additional questions concerning the interpretation of glove box data from North Ridge. Thus, these results are not further addressed here, except to the extent that the observed amphibole structures are included in the determination of the relative abundance of chrysotile and amphibole.

7.3.2.2. Assessing amphibole asbestos-related risks

Exposure and risk estimates for amphibole asbestos are presented in the bottom half of Table 9. Details of the layout for Table 9 and the sources of the data presented in the columns of the table have been previously described (Section 7.3.1). However, due to lack of observation of amphibole asbestos in any of the air samples from the special EPA study and the considerations addressed in the last section regarding the occurrence of amphibole asbestos in site soils, the amphibole asbestos source terms used to estimate both measured and modeled exposures in Table 9 had to be developed somewhat differently than that described for chrysotile.

To estimate "measured" exposure concentrations for amphibole asbestos, upper bound estimates were derived from the EPA study by multiplying the pooled analytical sensitivity for the set of runs from each exposure scenario by three. This was done because amphibole asbestos was not detected in any run and (as indicated in the footnotes to Table 1) three structures is the upper 95% confidence limit estimate to the observation of zero structures based on a Poisson distribution. In turn, the pooled analytical sensitivity is determined as the reciprocal of the sum of the reciprocal of the analytical sensitivities for each individual run in the data set (also as previously indicated).

To illustrate the above, the instantaneous exposure concentration of amphibole asbestos estimated for child's play (in terms of protocol structures) is determined as follows:

$$3 \times 1/(1/6.8E\text{-}03 + 1/1.5E\text{-}02) = 1.4E\text{-}02$$

Note that the manner in which time-adjusted exposure estimates and risk estimates are derived from the instantaneous exposure estimates for amphibole asbestos is identical to the manner in which these values are derived for chrysotile (which is described in detail in Section 7.3.1)

The UCL exposure and risk estimates derived from the measurements collected during the EPA study are presented in the bottom half of Table 9 in the rows labeled, "UCL." Because they are UCL's they are all shown as "less than."

So that exposure and risk estimates for amphibole asbestos could be modeled using the optimized models derived for child's play and rototilling (as described in Section 7.1 and 7.2, respectively), source concentrations for soils first had to be estimated.

As indicated in Table 3, the source concentration for amphibole asbestos was derived from the soil data of the EPA study as follows. First, by noting that only Sample No. 200 (of the four analyses conducted) exhibited observable amphibole asbestos, Sample 200 and its two duplicates were selected as the samples exhibiting the maximum observed concentration of amphibole (as opposed to sample 202, in which no amphibole was detected). Second, to be conservative, an upper bound estimate on the observed concentrations was derived by multiplying the pooled analytical sensitivity for the duplicate set (including sample 200, 201 and 201D) by 4.8, which is the 95% upper confidence limit to the observation of one structure based on a Poisson distribution. Note that, although two total amphibole structures were observed, only one protocol structure and one 7402 structure was observed.

The resulting source concentration estimates for amphibole asbestos are presented at the bottom of Table 3[18]. The corresponding exposure and risk

[18] Note that 3.7 str/μg_{PM10} (estimated here for amhibole asbestos) is approximately 3% of 120 str/μg_{PM10}, which is the concentration estimated for chrysotile in Section 6.3.1 and this is

estimates derived from these source concentrations using the optimized models for child's play and rototilling are presented in the bottom half of Table 9.

As can be seen from the amphibole asbestos-related risks presented in Table 9, in all cases, estimates derived using the optimum models are consistent with those derived from the measured data. However, because the measured data are derived as upper bound estimates on non-detected data, they are all presented as "less than" the indicated value.

As previously indicated, both the simulations and the modeled estimates are intended to be conservative relative to actual risks that may potentially be experienced when residents conduct the activities considered. However, conservatism is necessarily introduced into each of the two sets of estimates in a distinct manner. In both cases, this is done to account for the current lack of complete characterization of the degree of variation in conditions that may exist at the site.

The amphibole asbestos-related risk estimates presented in Table 9 are substantially higher than the risks estimated for chrysotile asbestos. Thus, even though they represent bounding estimates, so that actual risks are likely to be substantially lower, they fall into a range of potential concern. Even the one-year exposure estimates do not compare favorably to the EPA risk range of $1x10^{-4}$ to $1x10^{-6}$. In fact, when adjusted for early exposure, the one-year estimate for child's play exceeds the upper end of the EPA risk range.

These results suggest that immediate attention may be needed at the North Ridge Estates Site. Although, such concerns are somewhat mitigated by observations that:

- the amphibole asbestos-related risks presented in Table 9 are based on upper bound estimates that are essentially derived from the observation of a single structure in a soil sample collected during the special EPA study;
- the QC checks conducted on the EPA study data are not sufficient to eliminate concerns that some of the data may have been contaminated (Section 5.4.1.1); and
- at least in the case of the glove box study (where three of the six long ISO structures of amphibole asbestos were observed outside of Hot Spot No. 6), these data definitely need to be questioned because they are inconsistent with the results from a paired split of the sample analyzed by the Modified Elutriator method (Section 7.3.2.1).

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consistent with the findings of the relative occurence of amphibole asbestos in Section 6.3.2.1.

In addition to the above, the bounding risk estimates presented in Table 9 for amphibole asbestos can likely be reduced by at least a factor of three due to the same arguments presented at the end of Section 7.3.1 for chrysotile-related risks. Nevertheless, caution is clearly warranted.

8. CONCLUSIONS AND RECOMMENDATIONS

Given the bounding exposure and risk estimates provided in the last section, for now, it would be prudent to limit intimate contact with local soils (especially children playing in such soils). Although bounding risks estimated for exposure to chrysotile do not suggest the existence of an imminent hazard, the bounding risks estimated for exposure to amphibole asbestos, suggest otherwise. Despite the mitigating factors that have been identified for the bounding risks estimated for amphibole asbestos, prudence dictates that residential activities involving physical proximity to the soil while it is disturbed (such as when children play in dirt or adults garden) should be curtailed until either the magnitude of such risks can be better characterized and shown to be lower than the bounding estimates suggest or site mitigation is completed.

At the same time, it needs to be recognized that the bounding risk estimates developed for amphibole asbestos are based on UCL estimates derived from the detection of a total of six structures among all of the samples collected at the site. Moreover, three of these six structures were observed in a single sample that appears to have QC problems and was prepared using a procedure for which there is no established protocol to guide interpretation of the results. Therefore, it is highly likely that the bounding estimates provided in this document, particularly for amphibole asbestos, are extremely conservative relative to any actual exposures and risks that may occur at the site. Therefore, while prudence dictates caution, more data will clearly be required before any definitive conclusions can be drawn regarding exposure and risk at the site.

Importantly, the above recommendations should be considered in addition to (rather than supplanting) the recommendations provided in the Preliminary Soil Report.

Due to the unique concern suggested above for exposure to amphibole asbestos, some suggested information and guidance that may be helpful to site residents is presented in Appendix B. It is recommended that this information be shared with site residents sooner rather than later.

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